Non-Basaltic Early Lunar Magmatism. Charles A. Wood, Space Studies, University of North Dakota, Grand Forks, ND 58202. cwood@badlands.nodak.edu

The early history of the Moon was dominated by impact cratering and volcanic resurfacing. By 4.5 b.y. ago, the Moon had accreted by impact cratering that was a billion times more intense than today [1]. The energy of accretion provided enough heat to totally melt the Moon, or at least the top few hundred kilometers, causing the formation of the global anorthositic crust. Both cratering and magmatism declined, apparently at differing rates. By 3.8 b.y. cratering was reduced to rates only a few times higher than today, but mare volcanism was still intense for another 300 to 800 my years. As we look at the Moon today we can generally recognize and understand the volcanic and impact units since ~4.0 b.y.ago, but identification of the origins of earlier deposits are still controversial. I propose that mare volcanism was simply the last, and most distinct in albedo, phase of widespread early lunar magmatism. The only places that preserve the earlier volcanism are the lunar highlands.

Interpretation of the origin of relatively smooth, but high albedo materials of the near-side lunar highlands has ranged from volcanic to basin ejecta. Pre-Apollo 16 interpretations by USGS scientists [2] were that intercrater smooth plains were early volcanism, perhaps less mafic than mare basalts. The shock of Apollo 16, caused a dogmatic reversal of opinion to the belief that all such smooth units were basin ejecta. I argue here that not all intercrater plains and similar smooth fill within many highland craters are basin ejecta for a number of reasons. First, the crater fill material in the southern highland region near the craters Lilius, Zach and Cuvier is clearly younger (fewer impact craters and reduced roughness) than the surrounding intercrater plains. It is unlikely that only the craters were filled with basin ejecta, and it is also unlikely that the intercrater plains would be, but not the crater floors. Second, an older complex of interlocking craters between Zach and Deluc is completely embayed by smooth crater fill, with many rims missing - like small versions of flooded craters along many mare shores. Third, this area is relatively far from most basins and does not exhibit any visual variations in crater fill in one direction or another. These observations strongly argue that the highland crater fill in this region was emplaced individually within each crater as volcanic lava flows. And as argued above, the intercrater plains could not be covered by ejecta if the crater floors are not. The only way that the intercrater plains could be dominated by basin ejecta is if the crater fill is younger, and thus volcanic.

Another likely example of high albedo volcanic material is on the floor of the Schrödinger Basin. Hartmann and I [3] interpreted the smooth material that surrounds the peak ring to be volcanic. Using Clementine images Shoemaker and colleagues [4] proposed that the smooth plains inside the peak rings were fluid impact melt. No justification for this interpretation was given, although substantial impacts melts would be expected in a crater this large (320 km). However, Shoemaker's group also recognized on the central floor of Schrödinger three small patches of low albedo mare material, a dark halo maar-like crater, and a lobate ridge that they interpreted as being formed by viscous lava. With such obvious and varied evidence of actual volcanism, Occam's razor would require that the smooth plains also are most likely volcanic in origin. Instead of three different manifestations of volcanism here (mare lavas, pyroclastic eruptions and viscous lavas), I would argue that there was a fourth: non-mare composition, high albedo volcanic lava flows. In fact, the Shoemaker group's viscous ridge rises out of the smooth plains material and appears to be identical in texture and albedo to the plains. And they comment on the "remarkable" occurrence of ghost craters in the putative impact melt deposits; ghost craters are not at all remarkable in mare lavas. Finally, the lower illumination of the Orbiter V-21-H2 image reveals mare ridges on the smooth plains.

Shoemaker and colleagues used crater data to estimate ages for Schrödinger (including the smooth plains) as 3.8 b.y., the mare patches (~3.2 b.y.), and the dark halo vent (<~ 1 b.y.). I believe the interpretation of the smooth plains as high albedo lavas is most consistent with the evidence for prolonged and multi-styled volcanism.

There are many other highland locales where the geologic interpretation of high albedo smooth plains is consistent with volcanic origins. Compelling evidence of another type is provided by Hartmann's [5] demonstration that many broad regions of the lunar highlands have a deficiency of craters between diameters of roughly 1 and 32 km. He believes that these missing craters have been buried by plains resurfacing. The resulting "V" shaped crater diameter distribution curve is a signature of intercrater plains. Hartmann's team in the Basaltic Volcanism project [6] used different analyses of crater statistics to arrive at a similar conclusion that early volcanism was widespread on the Moon. And Hartmann and I [3] showed that the light-hued smooth plains had a range of crater densities and were not concentrated just at the ages of basins.

Based on the geologic and crater statistic evidence above, I reiterate that non-mare volcanism was pervasive in early lunar history and has left behind many clear examples that lunar scientists - over-reacting to the trauma of Apollo 16 - have ignored.

Accepting that non-mare volcanism occurred, what was its composition? An important negative observation is that the classic nearside highlands do not contain dark-halo craters of any size. In other words, whatever the origin and composition of highland smooth plains, they are not simply mare basalts veneered by highland ejecta from basins and craters. Another possible explanation is that the highland plains are made of KREEP volcanic rocks as in the light-hued Apennine Bench formation within the Imbrium basin, but the lunar highlands do not appear to have the high radioactivity of those lavas.

Mapping of Fe abundances from Clementine data shows that the surface highland rocks are anorthositic nearly everywhere [7]. By looking at central peaks, however, Pieters [8] found that at greater depths (5-15 km) the compositions are mostly gabbroic, anorthositic and troctolitic. These plutons may very well have been the magma chambers that fed early, non-basaltic eruptions which created the smooth crater floors and intercrater plains of the lunar highlands. The ages of such gabbroic and troctolitic fragments found in the Apollo samples range from 4.5 to 4.2 b.y. [9], exactly the likely time of emplacement of the postulated highland lavas.

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